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Effects of Forage Management on the Nutritive Value of Stockpiled Bermudagrass

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ABSTRACT

'Common' and 'Tifton 44' bermudagrass [*Cynodon dactylon* (L.) Pers.] located near Fayetteville and Batesville, AR, respectively, were chosen to evaluate the effects of stockpiling initiation date (August or September), and N fertilization rate (0, 37, 74, or 111 kg N ha^{-1}) on the nutritive value of fall-stockpiled bermudagrass. At the Fayetteville location, there were initiation × harvest date interactions for acid detergent fiber (ADF, $P = 0.003$), hemicellulose ($P = 0.003$), cellulose ($P = 0.0003$), lignin ($P = 0.007$), and crude protein (CP, $P = 0.008$) in 2000, and strong interactions ($P \leq 0.001$) for all response variables in 2001. Generally, neutral detergent fiber (NDF), ADF, cellulose, and lignin increased over harvest dates for both initiation dates in 2000, although increases for lignin were only numerical ($P > 0.05$) for the September initiation date. Similar responses were observed for the August initiation date in 2001, but fiber components for the September 2001 initiation date declined over time because of contamination by other winter-annual species. For August initiation dates in 2000 and 2001, in vitro organic matter disappearance (IVOMD) declined linearly ($P \leq 0.002$) over harvest dates, reaching respective minima of 330 and 361 g kg^{-1}. At the Batesville site, an N fertilization effect ($P \leq 0.017$) was observed for NDF, ADF, and CP in both 2000 and 2001. A similar effect was observed for lignin ($P = 0.001$) and IVOMD ($P < 0.0001$) in 2000, and for cellulose ($P = 0.0004$) during 2001. Fertilization with N at the initiation of stockpiling generally reduced fiber components, and increased CP; however, IVOMD was increased for 2000 only. As observed for the Fayetteville site, most fiber components increased over harvest dates, while IVOMD declined concomitantly. Generally, the nutritive value of stockpiled bermudagrass declines between mid-October and mid-December, and spring-calving beef cows in the Upper South may need to be supplemented with energy to maintain body condition in the late fall or early winter.

Beef cattle producers throughout Arkansas and the southeastern USA face many economic obstacles, which include the maintenance of cows throughout the winter months. Most producers throughout this region rely on bermudagrass as the primary warm-season forage during the summer growing season, and often utilize tall fescue (*Festuca arundinacea* Schreb.) during the spring and fall. Bermudagrass has the potential to produce high yields of forage throughout the summer, in part because it is highly responsive to fertilization with N (Doss et al., 1966; Hill et al., 1993). Traditionally, large quantities of this forage have been harvested as hay to maintain beef cows and other livestock during the winter months, but this management approach is costly. In contrast, autumn stockpiling is a management technique in which forage is allowed to accumulate throughout the late summer and early fall for subsequent grazing during the late fall and winter. Stockpiling is a management technique that can reduce the need for supplemental hay and its associated costs (Adams et al., 1994; D'Souza et al., 1990; Hitz and Russell, 1998). Although the practice of autumn stockpiling has been applied to perennial cool-season grasses generally (Riesterer et al., 2000; Cuomo et al., 2005), and to tall fescue specifically (Kallenbach et al., 2003; Burns and Chamblee, 2000a; 2000b); there also has been interest in adapting this technique for bermudagrass (Lalman et al., 2000; Scarbrough et al., 2001; Scarbrough et al., 2004).

Scarbrough et al. (2001) suggested that stockpiled bermudagrass should be used in northern Arkansas during a relatively short (60-d) window between mid-October and mid-December; after that time, the nutritive value becomes very poor. Previously, Lalman et al. (2000) suggested that the digestibility and concentrations of CP were generally adequate to meet the nutritional requirements of spring-calving cows during the first few weeks after frost. Despite these nutritional limitations, autumn-stockpiled bermudagrass offers considerable potential for reducing reliance on harvested forages and it could fill an important niche in the Upper South by providing forage in mid-to-late autumn when producers throughout the region are allowing tall fescue to accumulate before use during the winter.

Previously, the effects of N fertilization rate, stockpiling initiation date, and harvest date on the dry matter (DM) yield potential of Tifton 44 and common stockpiled bermudagrass forages were evaluated at Batesville and Fayetteville, AR, respectively (Scarbrough et al., 2004). Although DM yield was highly dependent on precipitation, this research effort also identified an early August initiation date and modest N fertilization as key management considerations for maximizing DM yield. However, it remains unclear how these factors may affect the nutritive value of these forages. The objectives of this study were to characterize the nutritive value of the autumn-stockpiled bermudagrass forages described

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; DM, dry matter; IVOMD, in vitro organic matter disappearance; NDF, neutral detergent fiber.

previously (Scarbrough et al., 2004). A secondary objective was to evaluate the ruminal in situ DM disappearance kinetics for forages harvested from selected treatments that appear to offer the best potential for maximizing forage DM yield.

MATERIALS AND METHODS

Description of Experimental Forages

A detailed description of experimental sites, treatments, plot and harvest management, and DM yield and canopy height of harvested fall-stockpiled bermudagrass forages were reported previously (Scarbrough et al., 2004). Briefly, 3.7 by 6.1 m plots of Tifton 44 and common bermudagrass were established in four field blocks during 2000 and 2001 at Batesville and Fayetteville, AR, respectively. Experimentally, it would have been better to utilize the same type of bermudagrass at both sites, but many popular hybrids, such as Tifton 44, are not grown commonly in the Fayetteville area. In part, this occurs because of potential for winterkill. Producers in the Fayetteville area most frequently utilize 'Greenfield' or common bermudagrasses of unknown origin that are well adapted to the colder climate in northwestern Arkansas. For these reasons, we selected bermudagrasses that were consistent with the hay-types used by producers in each area.

At both sites (Fayetteville and Batesville), the treatment structure included two stockpiling initiation dates (August or September), four N fertilization rates (0, 37, 74, or 111 kg N ha^{-1}) applied as ammonium nitrate (34–0–0) at the initiation of stockpiling, and four harvest dates that began in mid-October and continued at 3-wk intervals through mid-December. Specific dates for the initiation of stockpiling during 2000 were 8 August and 6 September at Fayetteville, and 10 August and 6 September at the Batesville site. For 2001, stockpiling initiation dates were 7 August and 4 September at Fayetteville, and 9 August and 6 September at Batesville. On each harvest date, plots were clipped to a 5-cm stubble height by cutting a single swath (0.9 by 3.7 m) across each plot with a self-propelled sickle-bar mower (Model Monarch, Year-A-Round Cab Corp., Mankato, MN). A subsample from each plot weighing approximately 1000 g was dried to constant weight under forced air (55°C) and then retained for subsequent laboratory analysis and ruminal incubation in situ.

Laboratory Analysis

All dried forages were ground through either a 1- or 2-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Portions of samples ground through a 1-mm screen were analyzed sequentially for NDF, ADF, hemicellulose, cellulose, and acid-detergent lignin by the batch procedures outlined by ANKOM Technology Corp. (Fairport, NY); both sodium sulfite and heat-stable α-amylase were omitted from the neutral detergent solution. Hemicellulose was calculated as 1000 g kg^{-1} × the weight lost between extractions in neutral and acid detergents divided by the original sample dry weight. Similarly, cellulose was determined as 1000 g kg^{-1} × the weight lost between extractions in acid detergent and 72% w/w H_2SO_4 divided by the original sample dry weight. Nitrogen was determined by rapid combustion (AOAC, 1998, Official Method 990.03; Elementar Americas, Mt. Laurel, NJ); CP was calculated by multiplying the concentration of N in the sample × 6.25. Subsamples ground through a 2-mm screen were stored in sealed freezer bags at room temperature pending ruminal incubation in situ.

In Situ Procedures

Based on the yield responses for these stockpiled bermudagrass forages (Scarbrough et al., 2004), the success of this production system is highly dependent on adequate precipitation during the accumulation period. An early August initiation date coupled with modest N fertilization will likely maximize yield of DM and limit risk. Therefore, stockpiled forages for which accumulation of DM was initiated in early August after fertilization with 74 kg N ha^{-1} were selected for intensive evaluation of ruminal degradation kinetics of DM. For this treatment combination, forage samples within each site-year were composited over field replications for each harvest date, thereby reducing the number of total forages to a manageable number (3 site-years × 4 harvest dates = 12 total forages) for this type of kinetic evaluation. Site-years included in this evaluation were Batesville 2001, and Fayetteville 2000 and 2001; because precipitation was 75 mm below normal for August 2000 at Batesville (Table 1), yields of DM were very poor (overall mean = 368 kg ha^{-1}; Scarbrough et al., 2004) and forages from this site-year were not incubated ruminally.

All cannulations and care of the steers were approved by the University of Arkansas Animal Care and Use Committee (Protocol 05005). Five 726 ± 53.8 kg ruminally cannulated crossbred (Gelbvieh × Angus × Brangus) steers were used to evaluate the in situ disappearance kinetics of stockpiled bermudagrass forages. Steers had continuous and unrestricted access to fresh water and were housed in individual 3.4 by 4.9 m pens with concrete floors that were cleaned regularly. Each experimental steer was offered a diet of bermudagrass hay (126 g kg^{-1} CP, 670 g kg^{-1} NDF, and 336 g kg^{-1} ADF) and a corn-based supplement (371 g kg^{-1} cracked corn [*Zea mays* L.]; 200 g kg^{-1} wheat [*Triticum aestivum* L.] middlings; 347 g kg^{-1} soybean [*Glycine max* L.] meal; 40 g kg^{-1} molasses; 34 g kg^{-1} trace mineral salt; 3 g kg^{-1} limestone; 2 g kg^{-1} Vitamin A, D, and E premix; and 3 g kg^{-1} Vitamin E). On an as-fed basis, the basal diet contained 850 g kg^{-1} bermudagrass hay and 150 g kg^{-1} concentrate, and was offered at 0630 and 1430 in equal portions at a cumulative daily rate of 20 g kg^{-1} of body weight. Steers were adapted to the basal diet for 10 d before initiating the trial.

Five-gram samples of each stockpiled bermudagrass forage were weighed into dacron bags (10 by 20 cm, 50 ± 10 μm pore

Table 1. Monthly average temperature and cumulative monthly precipitation for Fayetteville and Batesville, AR, during 2000 and 2001.

	Avg. temperature			Precipitation		
Month	2000	2001	Normal†	2000	2001	Normal
	°C			mm		
			Fayetteville			
July	25.8	27.8	26.3	73	106	80
Aug.	28.6	27.0	25.7	0	69	76
Sept.	22.4	20.1	21.3	142	167	123
Oct.	16.9	15.4	15.1	97	119	95
Nov.	6.2	11.7	8.5	168	108	120
Dec.	−2.4	5.1	3.3	30	134	81
Jan.	1.1	3.7	1.3	72	48	54
			Batesville			
July	27.3	29.0	27.9	24	126	80
Aug.	30.6	29.0	27.2	3	11	78
Sept.	24.7	22.5	23.3	52	98	94
Oct.	18.8	16.6	17.4	35	100	99
Nov.	9.0	13.4	10.8	161	146	135
Dec.	−0.7	7.2	5.4	101	247	102
Jan.	3.6	6.8	3.6	31	133	76

† NOAA (2002).

size, ANKOM Technology) that were heat sealed with an impulse sealer (Type TISH-200, TEWI International Co., Ltd., Taipei, Taiwan). Before insertion into the rumen, all dacron bags were placed in 35 by 50 cm mesh laundry bags and soaked in tepid water (39°C) for 20 min. Samples were then suspended in the ventral rumen immediately before the 0630 feeding and incubated for 3, 6, 9, 12, 24, 36, 48, 72, or 96 h. Upon removal from the rumen, bags were rinsed immediately in a top-loading washing machine (model LXR7144EQ1; Whirlpool Corp., Benton Harbor, MI). Rinsing procedures included six cold-water rinse cycles (47 L of water), where each cycle consisted of 1 min of agitation and 2 min of spin (Coblentz et al., 1997; Vanzant et al., 1998). A separate set of bags was pre-incubated and rinsed without ruminal incubation (0 h). After rinsing, the sample residues were dried to a constant weight under forced air at 50°C, and equilibrated with the atmosphere before further analysis for residual DM (Vanzant et al., 1996).

The proportion of DM remaining at each incubation time was fitted to the nonlinear regression model of Mertens and Loften (1980) using PROC NLIN of SAS (SAS Institute, 1990). Dry matter was partitioned into three fractions based on relative susceptibility to ruminal disappearance. Fraction A was defined as the immediately soluble portion, although it also may include some minute insoluble particles that may wash out of dacron bags (Coblentz et al., 1998; Galdámez-Cabrera et al., 2003). Fraction B represented that portion of DM that disappeared at a measurable rate, while Fraction C was defined as the portion of DM that was undegraded in the rumen. Fractions B and C, the disappearance rate, and the discrete lag time were determined directly by the nonlinear regression model. For each forage, Fraction A was calculated as 1000 g kg^{-1} − (B + C). For all forages, the effective ruminal disappearance of DM was calculated as $A + (B \times [K_d/(K_d + K_p)])$ (Ørskov and McDonald, 1979), where K_d = disappearance rate and K_p = passage rate (0.035 h^{-1}). This passage rate used in this study was based on other work with similar basal diets. Previously, Scarbrough et al. (2001), Galdámez-Cabrera et al. (2003), and McBeth et al. (2003) determined the passage rate of similar basal diets using acid detergent insoluble ash as an internal marker (Waldo et al., 1972). Respective estimates of passage rate using these procedures were 0.035 ± 0.0067 h^{-1}, 0.032 ± 0.0017 h^{-1}, and 0.039 ± 0.0021 h^{-1}; therefore, the mean (0.035 h^{-1}) of these estimates was used to calculate effective ruminal disappearance.

Statistical Analysis

Nutritive Value

Because the bermudagrass varieties and their respective growth characteristics were not the same across locations, data for each location were analyzed independently. Initially, the effects of year were included in the model, but there were numerous interactions ($P < 0.05$) of other treatment factors with year at both locations; therefore, each year was analyzed independently. Data within each site-year were analyzed as a split-plot design (PROC GLM; SAS Institute, 1990). Whole plots were arranged in a 2 × 4 factorial arrangement of treatments that included two initiation dates (August or September) and four fertilization rates (0, 37, 74, or 111 kg N ha^{-1}). The subplot treatment factor was autumn harvest date. Single degree of freedom orthogonal contrasts (PROC GLM; SAS Institute, 1990) were used to describe the effects of N fertilization rate and harvest date on characteristics of nutritive value.

Ruminal In Situ Degradation of Dry Matter

Kinetic data were evaluated as a randomized complete block design with steers (5) serving as the blocking term. Single degree of freedom orthogonal contrasts (PROC GLM; SAS Institute, 1990) were used to describe the effects of harvest date within each site-year on the kinetic characteristics of ruminal disappearance in situ.

RESULTS

Fayetteville 2000

For 2000, the main effect of N fertilization rate, and all interactions of other treatment effects with N fertilization rate had no effect ($P > 0.05$, Table 2) on any index of nutritive value. An interaction of initiation and harvest dates was observed ($P \leq 0.008$) for all indices of nutritive value, except for NDF and IVOMD ($P > 0.05$); because interactions of these treatment effects were found for most response variables, only interaction means are presented (Table 3) and discussed.

August Initiation Date

Concentrations of all fiber components changed over harvest dates, exhibiting cubic ($P \leq 0.029$) effects in

Table 2. Abbreviated ANOVA for indices of nutritive value for fall-stockpiled common bermudagrass harvested in Fayetteville, AR during 2000 and 2001.

Effect	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
	$P > F$						
			2000				
Initiation date (I)	<0.0001	<0.0001	NS†	0.0001	NS	<0.0001	<0.0001
N fertilization rate (Nrate)	NS	NS	NS	NS	NS	NS	NS
I × Nrate	NS	NS	NS	NS	NS	NS	NS
Harvest date (H)	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	0.038
I × H	NS	0.003	0.003	0.0003	0.007	0.008	NS
Nrate × H	NS	NS	NS	NS	NS	NS	NS
I × Nrate × H	NS	NS	NS	NS	NS	NS	NS
			2001				
Initiation date (I)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N fertilization rate (Nrate)	NS	NS	NS	NS	NS	NS	0.030
I × Nrate	NS	NS	NS	NS	NS	NS	NS
Harvest date (H)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.015	<0.0001
I × H	<0.0001	<0.0001	<0.0001	<0.0001	0.001	<0.0001	<0.0001
Nrate × H	NS	0.037	NS	NS	NS	NS	NS
I × Nrate × H	NS	NS	NS	NS	NS	NS	NS

† NS, not significant ($P > 0.05$).

Table 3. Initiation date × harvest date means for forage nutritive value of fall-stockpiled common bermudagrass forages harvested in Fayetteville, AR, during 2000.

Harvest date	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
	g kg^{-1}						
August initiation							
18 October	732	293	439	251	38.2	170	397
9 November	673	302	381	212	64.9	220	360
29 November	720	329	391	229	63.5	198	370
8 January†	735	331	404	228	75.8	183	330
SEM‡	4.8	3.4	6.3	3.5	3.52	3.6	13.4
Contrasts§	$P > F$						
Linear	0.014	<0.0001	0.001	0.001	<0.0001	NS¶	0.002
Quadratic	<0.0001	NS	<0.0001	<0.0001	0.044	<0.0001	NS
Cubic	<0.0001	0.005	0.029	<0.0001	0.010	<0.0001	NS
September initiation							
18 October	706	264	442	206	53.8	211	465
9 November	630	282	349	194	49.8	257	472
29 November	699	301	398	220	57.0	235	461
8 January	719	328	391	229	62.3	203	439
SEM	5.5	4.0	5.2	6.0	5.87	4.0	17.4
Contrasts	$P > F$						
Linear	<0.0001	<0.0001	<0.0001	0.001	NS	0.011	NS
Quadratic	<0.0001	NS	<0.0001	NS	NS	<0.0001	NS
Cubic	<0.0001	NS	<0.0001	0.046	NS	0.003	NS

† The final harvest for 2000 was delayed until 8 Jan. 2001 because of prolonged ice and snow cover (Scarbrough et al., 2004).
‡ Standard error of the mean.
§ Linear, quadratic, and cubic effects of harvest date.
¶ NS, not significant ($P > 0.05$).

each case. For NDF, ADF, hemicellulose, and cellulose, the minima were observed on the 9 November harvest date; this likely occurred because there was some continued release of new bermudagrass growth following the first harvest on 18 October. This release of new growth was facilitated by above normal rainfall in September and October, and temperatures that were well above normal during a 2-wk period immediately following 18 October (Table 1). Predictably, the maxima (220 g kg^{-1}) for CP also occurred on the 9 November harvest date, with an overall cubic ($P < 0.0001$) effect observed over the entire sampling period. Unlike all other measures of nutritive value, IVOMD declined linearly ($P = 0.002$) over harvest dates, ranging from 397 g kg^{-1} initially down to 330 g kg^{-1} on the final (8 January) harvest date.

September Initiation Date

Most fiber components and CP changed in patterns similar to those observed for August initiation dates. Cubic effects ($P \leq 0.046$) of harvest date were observed for NDF, hemicellulose, cellulose, and CP. For NDF, hemicellulose, and cellulose, the minimum concentrations occurred on the 9 November harvest date, which is consistent with observations made for the August initiation date. The inverse relationship was observed for CP, which exhibited a maximum of 257 g kg^{-1} on the same date. For stockpiled forages initiated in September, ADF in increased linearly ($P < 0.0001$) over time, ranging from 264 g kg^{-1} initially, to a maximum of 328 g kg^{-1} on the final harvest date. Unlike the August initiation date, lignin and IVOMD for stockpiled forages initiated in September exhibited no relationship ($P > 0.05$) with harvest dates.

Fayetteville 2001

As observed for 2000, N fertilization rate and its interactions with other treatment effects rarely affected ($P > 0.05$; Table 2) the nutritive value of stockpiled forages; the lone exceptions were an N fertilization rate for IVOMD ($P = 0.030$), and an interaction of N fertilization rate with harvest date ($P = 0.037$) for ADF. However, the interaction of stockpiling initiation and harvest dates affected ($P \leq 0.001$) all indices of nutritive value; therefore, results will be presented and discussed on the basis of these interaction means (Table 4).

August Initiation Date

Concentrations of NDF, ADF, cellulose, and lignin all increased over harvest dates. Cellulose and NDF increased in a linear ($P < 0.0001$) pattern over time, while cubic effects ($P \leq 0.021$) were observed for ADF and lignin. Crude protein declined minimally over harvest dates, ranging between 136 g kg^{-1} initially down to a minimum of 125 g kg^{-1} on 6 November; although these changes were relatively small, a cubic ($P = 0.036$) relationship with time was detected. Unlike all other indices of nutritive value, IVOMD declined in a strong linear ($P < 0.0001$) pattern that also exhibited a wide range (595–361 g kg^{-1}), thereby indicating that digestibility was depressed substantially over the sampling period.

September Initiation Date

Unlike trends over harvest dates for all other combinations of year, site, and stockpiling initiation date, most indices of nutritive value improved markedly over harvest dates because of contamination with winter an-

Table 4. Initiation date × harvest date means for forage nutritive value of fall-stockpiled common bermudagrass forages harvested in Fayetteville, AR, during 2001.

Harvest date	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
	g kg^{-1}						
August initiation							
17 October	673	302	371	260	30.3	136	595
6 November	694	328	366	269	39.8	125	500
27 November	713	330	383	271	42.8	130	445
18 December	727	361	366	279	52.5	126	361
SEM†	3.2	2.8	2.7	3.2	1.26	2.4	8.7
Contrasts‡	$P > F$						
Linear	<0.0001	<0.0001	NS§	<0.0001	<0.0001	0.020	<0.0001
Quadratic	NS	NS	0.025	NS	NS	NS	NS
Cubic	NS	<0.0001	<0.0001	NS	0.021	0.036	NS
September initiation							
17 October	620	249	371	208	22.5	205	696
6 November	559	263	296	195	32.2	224	636
27 November	430	197	233	164	17.9	231	775
18 December	439	224	215	154	29.5	236	791
SEM	7.4	4.9	6.2	4.2	3.51	5.7	10.1
Contrasts	$P > F$						
Linear	<0.0001	<0.0001	<0.0001	<0.0001	NS	0.001	<0.0001
Quadratic	<0.0001	NS	<0.0001	NS	NS	NS	0.001
Cubic	<0.0001	<0.0001	NS	0.040	0.003	NS	<0.0001

† Standard error of the mean.
‡ Linear, quadratic, and cubic effects of harvest date.
§ NS, not significant ($P > 0.05$).

nual weeds, particularly annual ryegrass (*Lolium multiflorum* Lam.), that comprised >50% of the total forage DM. This specific response was unique, and represented the only combination of initiation date, site, and year where contaminating species significantly affected DM yield (Scarbrough et al., 2004) or forage nutritive value. Concentrations of NDF, ADF, and cellulose declined substantially over harvest dates, each exhibiting a cubic ($P \leq 0.040$) response; hemicellulose also declined, exhibiting a quadratic ($P < 0.0001$) effect. Reductions over harvest dates for these fiber components were relatively large. Between the first and last harvest date, NDF, ADF, hemicellulose, and cellulose declined by 29, 10, 42, and 26%, respectively, indicating stockpiled bermudagrass was diluted substantially by annual ryegrass and other weeds. The effects of dilution by winter-annual contaminants also was evident for CP and IVOMD, which increased linearly ($P = 0.001$) by 15%, and cubically ($P < 0.0001$) by 14%, respectively, over the entire sampling period.

Batesville 2000

For bermudagrass forages at Batesville during 2000, N fertilization rate affected ($P \leq 0.001$) all indices of nutrient value except hemicellulose and cellulose ($P > 0.05$, Table 5). In addition, there was a significant effect ($P \leq 0.0001$) of harvest date for all response variables, but interactions of main effects generally were not observed ($P > 0.05$). For these reasons, only main effect means of N fertilization rate and harvest date are presented (Tables 6 and 7, respectively).

Table 5. Abbreviated ANOVA for indices of nutritive value for fall-stockpiled Tifton 44 bermudagrass harvested in Batesville during 2000 and 2001.

Effect	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
	$P > F$						
2000							
Initiation date (I)	NS†	NS	NS	NS	NS	0.001	0.006
N fertilization rate (Nrate)	0.001	0.0002	NS	NS	0.001	<0.0001	<0.0001
I × Nrate	NS	NS	NS	NS	NS	NS	NS
Harvest date (H)	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001
I × H	NS	NS	NS	NS	NS	0.009	NS
Nrate × H	NS	NS	0.011	NS	NS	NS	NS
I × Nrate × H	NS	NS	NS	NS	NS	NS	NS
2001							
Initiation date (I)	<0.0001	0.009	<0.0001	0.0001	0.027	<0.0001	<0.0001
N fertilization rate (Nrate)	0.017	0.0003	NS	0.0004	NS	<0.0001	NS
I × Nrate	NS	NS	NS	NS	NS	NS	NS
Harvest date (H)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.0001
I × H	0.001	NS	0.004	0.013	0.021	NS	NS
Nrate × H	NS	NS	NS	NS	0.037	NS	NS
I × Nrate × H	NS	NS	NS	NS	NS	NS	NS

† NS, not significant ($P > 0.05$).

Table 6. Nitrogen fertilization rate effect on nutritive value of fall-stockpiled Tifton 44 bermudagrass harvested in Batesville, AR, during 2000 and 2001.

N fertilization rate	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
kg N ha^{-1}				g kg^{-1}			
2000							
0	760	352	413	273	55.7	131	386
37	738	326	412	255	49.8	166	497
74	734	314	420	250	46.6	173	505
111	738	324	414	253	49.1	173	494
SEM†	4.0	4.9	6.1	2.7	1.35	4.7	11.0
Contrasts‡				$P > F$			
Linear	0.001	0.0003	NS§	<0.0001	0.001	<0.0001	<0.0001
Quadratic	0.004	0.002	NS	0.001	0.005	0.001	<0.0001
Cubic	NS	NS	NS	NS	NS	NS	NS
2001							
0	716	358	358	291	40.0	110	521
37	713	353	359	281	41.4	118	504
74	702	339	363	273	40.6	135	533
111	688	321	366	260	42.3	148	531
SEM	6.2	5.3	4.2	4.2	1.18	3.0	11.5
Contrasts				$P > F$			
Linear	0.002	<0.0001	NS	<0.0001	NS	<0.0001	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS
Cubic	NS	NS	NS	NS	NS	NS	NS

† Standard error of the mean.
‡ Linear, quadratic, and cubic effects of N fertilization rate.
§ NS, not significant ($P > 0.05$).

Initiation Date

For both CP and IVOMD, there was an effect of initiation date; CP for forages initiated in September exceeded ($P = 0.001$) those initiated in August by 18 g kg^{-1} (170 vs. 152 g kg^{-1}, data not shown). Similarly, IVOMD for forages initiated in September were greater ($P = 0.006$) by 33 g kg^{-1} (487 vs. 454 g kg^{-1}, data not shown) than those initiated in August.

Nitrogen Fertilization Effects

Excepting hemicellulose ($P > 0.05$), all fiber components declined in a quadratic ($P \leq 0.005$) pattern over N fertilization rates (Table 6). Generally, declines of 18 to 26 g kg^{-1} in concentrations of NDF, ADF, and cellulose occurred between the 0 and 37 kg N ha^{-1} fertilization rates, which were followed by relatively static responses thereafter. A similar declining pattern was observed for lignin, but the concentration differed by only 5.9 g kg^{-1} between the 0 and 37 kg N ha^{-1} fertilization rates. Concomitantly, both CP and IVOMD increased quadratically ($P \leq 0.001$) by 42 and 108 g kg^{-1}, respectively, over all fertilization rates. As observed for most fiber components, there were substantial changes for CP and IVOMD (35 and 111 g kg^{-1}, respectively) between the 37 kg N ha^{-1} fertilization rate and the unfertilized control, but responses were mostly static across higher N fertilization rates.

Harvest Date Effect

Generally, most fiber components increased during the sampling period (Table 7), but patterns of response ranged from a simple linear increase ($P < 0.0001$) for ADF to cubic ($P \leq 0.016$) effects for NDF, cellulose, and lignin. A cubic effect ($P < 0.0001$) also was observed for hemicellulose, but the overall range was relatively narrow (400–423 g kg^{-1}). Similarly, CP changed cubically ($P < 0.0001$) across harvest dates, but the range also was relatively narrow (155–170 g kg^{-1}), and a difference of only 7 g kg^{-1} separated responses on the initial and final

Table 7. Harvest date main effect on concentrations of fiber components, CP, and IVOMD for fall-stockpiled Tifton 44 bermudagrass harvested in Batesville, AR, during 2000.

Harvest date	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
				g kg^{-1}			
19 October	731	307	423	259	41.3	156	554
10 November	719	324	400	239	51.5	170	471
30 November	762	339	423	263	59.4	155	424
9 January†	758	346	412	272	49.1	163	433
SEM‡	3.1	3.3	4.0	2.7	1.4	2.0	9.9
Contrasts§				$P > F$			
Linear	<0.0001	<0.0001	NS¶	<0.0001	<0.0001	NS	<0.0001
Quadratic	NS	NS	NS	<0.0001	<0.0001	NS	<0.0001
Cubic	<0.0001	NS	<0.0001	<0.0001	0.016	<0.0001	NS

† The final harvest for 2000 was delayed until 9 Jan. 2001 because of prolonged ice and snow cover (Scarbrough et al., 2004).
‡ Standard error of the mean.
§ Linear, quadratic, and cubic effects of harvest date.
¶ NS, not significant ($P > 0.05$).

sampling dates. In contrast to all other indices of nutrient value, IVOMD declined sharply, exhibiting a quadratic ($P < 0.0001$) pattern that ranged from 554 g kg^{-1} initially down to 433 g kg^{-1} on the final sampling date.

Batesville 2001

For 2001, all indices of nutrient value were affected ($P \leq 0.027$) by initiation date, and all except CP ($P > 0.05$) were affected ($P \leq 0.0001$) by harvest date (Table 5). Unlike responses observed for 2000, an interaction of these main effects was observed for NDF ($P = 0.001$), hemicellulose ($P = 0.004$), cellulose ($P = 0.013$), and lignin ($P = 0.021$); therefore only interactions means for these treatment effects are reported and discussed (Table 8). As observed for 2000, fertilization with N affected concentrations of several forage fractions, including NDF ($P = 0.017$), ADF ($P = 0.0003$), cellulose ($P = 0.0004$), and CP ($P < 0.0001$), but interacted with other treatment effects (harvest date) only for lignin ($P = 0.037$). Therefore, only main effects of N fertilization rate are presented (Table 6).

Nitrogen Fertilization Effects

In contrast to responses for 2000, no higher order effects ($P > 0.05$) were observed for any response variable (Table 6). Linear decreases in NDF ($P = 0.002$), ADF ($P < 0.0001$), and cellulose ($P < 0.0001$), and an increase in CP ($P < 0.0001$), were observed in response to N fertilization; other fiber components and IVOMD were not affected ($P > 0.05$). Although these linear responses were statistically significant, they were limited in magnitude for the fiber components, ranging from 28 to 37 g kg^{-1} across N fertilization rates. For CP, the response to N fertilization was sharper; concentrations increased by 35% between the 0 and 111 kg N ha^{-1} fertilization rates.

August Initiation Date

All indices of nutrient value except CP varied ($P \leq 0.004$, Table 8) over harvest dates, but the pattern was inconsistent across response variables. Excepting hemicellulose, concentrations of fiber components increased generally over harvest dates, but the magnitude of response for some, especially NDF and cellulose, was limited (overall range = 42 and 28 g kg^{-1}, respectively); however, a strong linear decline of 31% (182 g kg^{-1}) was observed over sampling dates for IVOMD.

September Initiation Date

As observed for the August initiation date, all nutritive fractions except CP varied ($P \leq 0.024$) over harvest dates, mostly in patterns similar to those described for the August initiation date (Table 8). One notable exception was NDF, which declined quadratically ($P = 0.001$), reaching a minimum of 646 g kg^{-1} on the final harvest date. Although NDF, hemicellulose, and cellulose declined sharply at the end of the sampling period, IVOMD declined linearly ($P < 0.0001$) throughout, reaching a minimum of 506 g kg^{-1} on the final harvest date.

Dry Matter Disappearance Kinetics

Fractions A, B, and C

For stockpiled bermudagrass initiated in August and fertilized with 74 kg N ha^{-1} at Fayetteville in 2000 and 2001 and Batesville in 2001, Fraction A varied ($P \leq 0.015$) over harvest dates (Table 9), exhibiting multiple polynomial effects in each case. Although the pattern of

Table 8. Initiation date × harvest date means for forage nutritive value of fall-stockpiled Tifton 44 bermudagrass forages harvested in Batesville, AR, during 2001.

Harvest date	NDF	ADF	Hemicellulose	Cellulose	Lignin	CP	IVOMD
				g kg^{-1}			
August initiation							
18 October	710	311	399	269	32.5	119	588
7 November	752	350	402	297	41.5	112	508
29 November	717	372	345	294	48.3	117	440
19 December	732	369	363	283	47.7	115	406
SEM†	6.8	6.7	4.4	6.0	1.59	4.6	14.5
Contrasts‡				$P > F$			
Linear	NS§	<0.0001	<0.0001	NS	<0.0001	NS	<0.0001
Quadratic	NS	0.003	NS	0.002	0.004	NS	NS
Cubic	0.0001	NS	<0.0001	NS	NS	NS	NS
September initiation							
18 October	681	306	375	261	30.3	143	635
7 November	717	326	391	275	33.0	135	574
29 November	682	366	316	288	49.6	139	522
19 December	646	343	303	241	45.7	141	506
SEM	10.0	9.2	7.7	6.8	1.71	6.0	13.0
Contrasts				$P > F$			
Linear	0.003	0.001	<0.0001	NS	<0.0001	NS	<0.0001
Quadratic	0.001	0.024	NS	<0.0001	NS	NS	NS
Cubic	NS	NS	<0.0001	NS	<0.0001	NS	NS

† Standard error of the mean.
‡ Linear, quadratic, and cubic effects of harvest date.
§ NS, not significant ($P > 0.05$).

Table 9. Ruminal in situ DM degradation characteristics for fall-stockpiled common bermudagrass harvested during 2000 and 2001 at Fayetteville, and for Tifton 44 bermudagrass harvested during 2001 at Batesville, AR. Yields of DM at Batesville during 2000 were very poor, and forages harvested in 2000 were not evaluated in situ. Fall stockpiling at each site-year was initiated in early August and fertilized with ammonium nitrate at a rate of 74 kg N ha^{-1} on the stockpiling initiation date.

Year/harvest date	Fraction A†	Fraction B	Fraction C	Lag time	K_d	Effective disappearance‡
	g kg^{-1}	g kg^{-1}	g kg^{-1}	h	h^{-1}	g kg^{-1}
Fayetteville 2000						
18 October	131	555	313	1.90	0.038	419
9 November	217	366	417	0.65	0.031	386
29 November	180	425	395	1.23	0.035	393
8 January	169	445	386	1.86	0.042	410
SEM§	4.9	8.2	7.3	0.517	0.0016	4.9
Contrasts¶	P > F					
Linear	0.005	<0.0001	<0.0001	NS#	0.040	NS
Quadratic	<0.0001	<0.0001	<0.0001	NS	0.001	0.0003
Cubic	<0.0001	<0.0001	0.001	NS	NS	NS
Fayetteville 2001						
17 October	217	482	301	1.43	0.044	484
6 November	170	453	377	1.69	0.037	400
27 November	149	466	386	1.69	0.035	378
18 December	182	378	441	1.33	0.031	356
SEM	3.8	5.4	3.5	0.513	0.0013	3.9
Contrasts						
Linear	<0.0001	<0.0001	<0.0001	NS	<0.0001	<0.0001
Quadratic	<0.0001	<0.0001	0.015	NS	NS	<0.0001
Cubic	NS	<0.0001	<0.0001	NS	NS	0.005
Batesville 2001						
18 October	188	549	263	2.60	0.039	476
7 November	142	597	261	2.08	0.036	442
29 November	189	477	334	1.32	0.035	428
19 December	191	449	360	1.20	0.030	397
SEM	4.5	12.2	9.1	0.369	0.0020	5.9
Contrasts	P > F					
Linear	0.015	<0.0001	<0.0001	0.011	0.012	<0.0001
Quadratic	0.0002	0.009	NS	NS	NS	NS
Cubic	<0.0001	0.0004	0.011	NS	NS	NS

† Abbreviations: A = immediately soluble fraction, B = fraction degradable at a measureable rate, C = undegradable fraction, and K_d = fractional degradation rate.
‡ Calculated as A + (B × [K_d / K_d + passage rate]), where K_d = ruminal degradation rate and passage rate = 0.035 h^{-1}.
§ Standard error of harvest date means (n = 5 steers).
¶ Linear, quadratic, and cubic effects of harvest date.
# NS, not significant ($P > 0.05$).

response was distinct for each site-year, the mean proportion of DM that was immediately soluble varied little between site-years (overall range = 174–180 g kg^{-1}). This represents a relatively small proportion of total DM relative to legumes (Coblentz et al., 1998), but this characteristic is typical of perennial warm-season grasses generally (Coblentz et al., 1998; Galdámez-Cabrera et al., 2003; McBeth et al., 2003), and for stockpiled bermudagrass specifically (Scarbrough et al., 2001). Generally, Fraction B declined over harvest dates for each site-year, but the relationship was cubic ($P \leq 0.0004$) in each case. For Fayetteville during 2000 and 2001, Fraction B ranged between 366 and 555 g kg^{-1}, and between 449 and 597 g kg^{-1} for Batesville in 2001; these ranges generally represent a greater proportion of total forage DM than reported by Scarbrough et al. (2001) for ungrazed hay (275–439 g kg^{-1}) and pasture (256–453 g kg^{-1}) sites sampled over a similar time interval. This may be explained on the basis of reduced stem development and poorer yields in the present study, during which weather conditions were generally droughty (Table 1). Fraction C, which represents the proportion of forage DM unavailable in the rumen, increased for each site-year in a cubic ($P \leq 0.011$) pattern over harvest dates. Increased rumen unavailability is expected with aging and/or weathering during the fall and winter, and this response is consistent with that reported previously for autumn-stockpiled bermudagrass (Scarbrough et al., 2001).

Lag Time

Harvest dates had no effect ($P > 0.05$) on lag time for the Fayetteville site in either year (Table 9). Generally, lag times were relatively short, averaging 1.41 and 1.51 h, respectively, for these site-years. For Batesville in 2001, lag times declined linearly ($P = 0.011$) over harvest dates, but the overall mean (1.80 h) also was relatively short, and generally comparable to other site-years.

Ruminal Disappearance Rate (K_d)

Estimates of K_d exhibited a quadratic ($P = 0.001$) relationship with harvest date at Fayetteville during 2000, ranging from a minimum of 0.031 h^{-1} on the second harvest date to a maximum of 0.042 h^{-1} on the final harvest date (Table 9). In contrast, K_d declined linearly ($P \leq 0.012$) over harvest dates at both sites in 2001, ranging from 0.044 to 0.031 h^{-1} for Fayetteville, and from 0.039 to 0.030 h^{-1} at Batesville. The magnitude of K_d for all site-years (overall mean = 0.037, 0.037, and 0.035 h^{-1} for Fayetteville 2000, Fayetteville 2001, and Batesville 2001, respectively) is very consistent with other estimates for spring and summer growth of bermudagrass harvested in northwestern Arkansas (Galdámez-Cabrera et al., 2003; McBeth et al., 2003), and for fall-stockpiled bermudagrass grown in the same region (Scarbrough et al., 2001).

Effective Ruminal Disappearance

The effective ruminal disappearance of stockpiled bermudagrass changed in a quadratic ($P = 0.0003$) pattern over harvest dates for Fayetteville during 2000 (Table 9); however, the biological significance of this response is questionable because the overall range was narrow (386–419 g kg^{-1}). For Fayetteville and Batesville during 2001, respective estimates of effective disappearance declined in cubic ($P = 0.005$) and linear ($P < 0.0001$) patterns over the sampling period. Across all harvest dates and site-years, the effective ruminal disappearance ranged from 356 to 484 g kg^{-1}. This is similar to other estimates for fall-stockpiled bermudagrass (Scarbrough et al., 2001), but is somewhat less than reported by Galdámez-Cabrera et al. (2003) for common bermudagrass harvested in Arkansas during May (513–553 g kg^{-1}) and August (490–517 g kg^{-1}).

DISCUSSION

Harvest Date

The effect of weathering was associated generally with increased concentrations of all fiber components, except hemicellulose. Although there was an increasing overall trend for concentrations of fiber components, these relationships were often complex, resulting in multiple and/or higher order polynomial effects that were inconsistent across initiation dates, sites, and years. Hemicellulose also changed over harvest dates, but trends were less clear, sometimes decreasing over time. Several factors could contribute to these complex and inconsistent responses. One factor is simply the inconsistent weather patterns across sites and years; rates of nutritional decline for fall-stockpiled bermudagrass may be accelerated with high winter precipitation (Lalman et al., 2000). Another potential factor may have been the release of immature bermudagrass tillers following weather conditions favorable for growth; this was observed for some site-years after the initial harvest date in mid October.

Nitrogen Fertilization

Generally, neither N fertilization nor its associated interactions with other treatment effects affected indices of nutritive value at the Fayetteville site. In contrast, slight reductions in concentrations of all fiber components, except hemicellulose, were observed for the Batesville site during both years. Previously, Galdámez-Cabrera et al. (2003) reported that NDF declined linearly at a rate of 0.08 g kg^{-1} per kg N ha^{-1} of fertilization for common bermudagrass harvested during May and August in northwest Arkansas. By comparison, the rate of decline for NDF in fall-stockpiled forage harvested at Batesville during 2001 was about 0.25 g kg^{-1} per kg N ha^{-1} of fertilization; however, the decline for 2000 was quadratic ($P = 0.004$), occurring primarily between the 0 and 37 kg N ha^{-1} fertilization rates.

Strong increases in CP were observed with N fertilization in Batesville during both years, but the pattern across harvest dates was inconsistent. A quadratic effect ($P = 0.001$; Table 6) was observed for 2000, while a linear ($P < 0.0001$) increase was found for 2001. Other studies (Johnson et al., 2001; Coblentz et al., 2004) have reported that CP in bermudagrass forages is increased with N fertilization during the summer months; however, CP was not affected by fertilization rate at the Fayetteville site in either year. While reasons for the general lack of response to fertilization with N at Fayetteville remain unclear, it is possible that the Fayetteville site's past history of repeated applications of livestock manure and/or lounging by cattle contributed pools of residual organic N to the soil, thereby masking any effect of N fertilization. Despite these inconsistent responses, CP for all sites, years, and initiation dates remained in excess of the requirements for nonlactating, spring-calving beef cows (NRC, 1996).

IMPLICATIONS

Digestibility estimates for fall-stockpiled bermudagrass suggest that forages with minor contamination by winter-annual grasses and broadleaf weeds exhibited limited digestibility during the late fall and early winter. Within a specific site-year, the initial IVOMD in mid-October varied over a range of more than 200 g kg^{-1}, and declined to different minima (potentially <400 g kg^{-1}), depending on the magnitude of the initial estimate, and the ensuing weather conditions. Producers in the Upper South can best utilize stockpiled bermudagrass by grazing nonlactating, spring-calving beef cows during a window of approximately 60 d between mid-October and mid-December. During that time interval, some supplementation with energy sources may be required to maintain body condition, but concentrations of CP are likely to be more than adequate for nonlactating cows. After mid-December, cows can more easily be maintained on stockpiled cool-season forages, such as tall fescue, or in drylot on harvested forages.

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